Children's social referencing reflects sensitivity to graded uncertainty

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Abstract

The ability to monitor epistemic uncertainty is critical for self-directed learning. However, we still know little about young children's ability to detect uncertainty in their mental representations. Here we asked whether a spontaneous information gathering behavior – social referencing – is driven by uncertainty during early childhood. Children ages 2-5 completed a word-learning task in which they were presented with one or two objects, heard a label, and were asked to put the labeled object in a bucket. Referential ambiguity was manipulated through the number of objects present and their familiarity. In Experiment 1, when there were two novel objects and a novel label, the referent was ambiguous; when there were two familiar objects, or only one novel or familiar object, the referent was known or could be inferred. In Experiment 2, there were either two novel objects, two familiar objects, or one familiar and one novel object; in the latter case the referent could be inferred by excluding the familiar object. To further manipulate the availability of referential cues, the experimenter gazed at either the target or the center of the table while labeling the object. In both experiments, children looked at the experimenter more often while making their response when the referent was ambiguous. In Experiment 2, children also looked at the experimenter more when there was one familiar and one novel object, but only when the experimenter's gaze during labeling was uninformative. These results suggest that children's social referencing is a sensitive index of graded epistemic uncertainty.

Keywords: social referencing; help seeking; word learning; uncertainty.

Human learning can be characterized as a problem of detecting and reducing epistemic uncertainty. Being able to detect uncertainty in our own knowledge allows us to reduce that uncertainty by seeking disambiguating information or communicating uncertainty to social partners. Uncertainty monitoring may be particularly critical early in life, when children are tasked with learning their native language, the social and cultural structure of their world, and the causal properties of their environment. However, there has been mixed evidence about the extent to which young children are conscious of their own knowledge and mental states, and their ability to act on this meta-awareness (Schneider, 2008; Sodian, Thoermer, Kristen, & Perst, 2012). Do preschool-aged children monitor uncertainty and guide their learning behaviors on the basis of this monitoring, or is early learning better characterized as a process of integrating information that is largely generated externally, for example, by social partners who act as teachers (Csibra & Gergely, 2006)?

Research within a metacognitive framework has provided mixed evidence about whether young children can introspect on uncertainty. For example, preschool-aged children fail at reporting on their ongoing thoughts (J. H. Flavell, Green, Flavell, Harris, & Astington, 1995), and 3-year-olds report being equally sure about correct and incorrect responses in a memory task (Hembacher & Ghetti, 2014). Other studies have shown that preschoolers can distinguish between their own correct and incorrect answers in other tasks, although they are typically overconfident (Hembacher & Ghetti, 2014; Lyons & Ghetti, 2013; Paulus, Proust, & Sodian, 2013). There is also protracted development throughout childhood of other metacognitive abilities, such as estimating future performance (Destan, Hembacher, Ghetti, & Roebers, 2014; Lipowski, Merriman, & Dunlosky, 2013) and selectively allocating learning time to difficult or less-well-learned materials (Metcalfe & Finn, 2013). However, most of these studies have relied upon explicit reports of uncertainty or learning progress. It is possible that children are able to respond appropriately to uncertainty prior to their ability to bring it fully into consciousness or explicitly report on it.

In support of this possibility, several studies have shown that infants and toddlers engage in spontaneous information-seeking behaviors selectively in response to epistemic uncertainty. For example, Call and Carpenter (2001) had 2-year-olds choose between several tubes to find a hidden sticker. They found that the toddlers were more likely to peek inside a tube before choosing when they had not seen the baiting of the tubes compared to when they had, suggesting they were aware of their ignorance and managed to delay their response until they had a good answer. In another study, Goupil, Romand-Monnier, & Kouider (2016) found that 20-month-olds were more likely to seek help by looking at their parents when they were unable to respond accurately in a memory task. These implicit measures may better capture uncertainty signals by bypassing the need to orchestrate an explicit response, even a non-verbal one. Thus, examining spontaneous information-gathering behaviors may resolve remaining questions about young children's ability to monitor uncertainty, including uncertainty generated by graded evidence in different learning scenarios.

Here, we focus on the role of uncertainty in guiding social referencing – one form of information gathering – during word learning. One of the cues children have available to them when learning object-label mappings is the direction of a speaker's gaze, as people tend to look at objects they are referring to. By the second year of life infants follow a speaker's gaze and map labels to objects on the basis of gaze direction (D. A. Baldwin, 1991). There is also evidence that infant's propensity for gaze-following predicts later language development (Carpenter, Nagel, Tomasello, Butterworth, & Moore, 1998), highlighting the importance of this behavior for learning.

Although gaze-following is clearly critical for word-object

mapping, at any given moment, there are many stimuli in the visual field that compete for attention. In some cases, a listener may be required to disengage from a salient or informative stimulus in order to reference a speaker's gaze direction to resolve referential ambiguity. Thus, it may be optimal to follow a speaker's gaze only when disambiguating information is needed, which would require the listener to monitor her own uncertainty. Investigating the selectivity of gaze-following and social referencing in general may be a particularly useful case study of uncertainty monitoring processes for several reasons. Importantly, social referencing is a ubiquitous spontaneous behavior across the lifespan, and thus is ecologically valid.

Do infants and children follow a speaker's gaze regardless of the need for disambiguation, or do they selectively follow gaze when the referent of a word is unknown? Vaish, Demir and Baldwin (2011) investigated this question with 13- and 18-month-olds infants. Infants sat across from an experimenter who produced a label (e.g., "a modi!) in the presence of one or two objects. They found that infants looked up to the experimenter more often when there were two objects present, and the referent was thus ambiguous. They interpret this to mean that infants recognize when they need disambiguating information and reference gaze accordingly. In addition, when only one object was present, infants successfully mapped the new label to the object, as confirmed in a comprehension test in which children had to place a named object in a bucket. In sum, infants appear to selectively reference a speaker when uncertainty about the referent of a label is high.

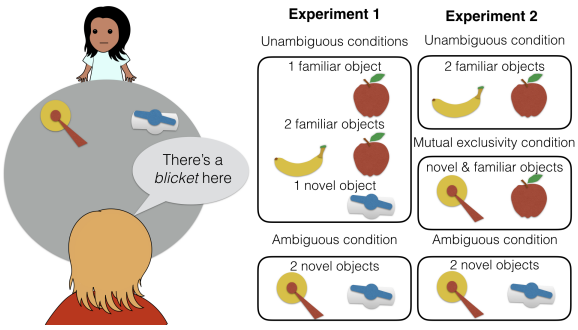

Figure 1: Study design for Experiments 1 and 2.

Experiment 1

The present research adapts the method of Vaish et al. to examine whether preschool-aged children's social referencing is sensitive to uncertainty based on referential ambiguity, and whether it reflects graded uncertainty about a word-object mapping. In Experiment 1, we examined whether children would reference a speaker more often when she produced a referentially ambiguous label. Children sat across from an experimenter who labeled an object on the table between them (Figure 1). Across trials, there were either one or two objects on the table, which were either familiar or unfamiliar to the child. We expected children to be uncertain about the label's referent only on trials with two unfamiliar objects, when the object-label mapping was not known and could not be inferred. After labeling an object, the experimenter asked the child to place the named object in a bucket.

We were interested in the amount of social referencing children exhibited across the trial. We considered four different phases of each trial based on the notion that children might expect different social information at different stages of the task. Specifically, we predicted that children might expect the speaker's gaze direction to be informative during the labeling itself, as speakers tend to look at objects they refer to. We predicted that later in the trial, as children reached for an object and placed it in the bucket, children might expect confirmation of the accuracy of their choice. We were interested in whether children would reference the speaker to a greater degree across these phases when referential ambiguity was high, which would indicate sensitivity to epistemic uncertainty.

Methods

Participants We recruited a planned sample of 80 children ages 2-5 years from the Children's Discovery Museum in San Jose, California[1]. The sample included 20 2-year-olds (mean age 31.71 months), 20 3-year-olds (mean age 42.65 months), 20 4-year-olds (mean age 55.85 months), and 20 5-year-olds (mean age 65.11 months). An additional 20 children participated but were removed from analyses because they heard English less than 75% of the time at home (n = 10), because they were unable to complete at least half of the trials in the task (n = 4), because of parental interference (n = 1), or due to experimenter or technical errors (n = 5).

Stimuli and Design Children were presented with one or two objects, heard a label, and were asked to put the labeled object in a bucket. Half of the objects were selected to be familiar to children (e.g., a cow) and half were selected to be novel (e.g., a nozzle). There were four trial types: one-familiar, one-novel, two-familiar, and two-novel. There were three trials of each type, for a total of twelve trials. Trial types were presented sequentially in an order that was counterbalanced across participants. The assignment of individual objects to trial types was counterbalanced. On familiar trials, the familiar label for the target object was used (e.g., "cow"). On novel trials, a novel label was used (e.g., "dawnoo").

The critical manipulation was of referential ambiguity; on one-familiar and two-familiar trials, there was no referential ambiguity, as children were expected to be certain about the objects and their labels. Similarly, on one-novel trials, children were expected to be certain about the label referent as there was only one option. However, on two-novel trials, the referent was ambiguous, as the novel label could apply to either novel object.

[1]Planned sample size, exclusion criteria, and analysis plan preregistered at `https://osf.io/y7mvt`

Procedure Throughout the study, the child sat at one end of a large circular table, and the experimenter stood at the opposite end. Each trial of the task proceeded as follows: the experimenter placed one or two objects on the left and/or right sides of the table, out of reach of the child so that the child could not interact with the toys during the labeling event. For one-object trials, the location of the object (left or right) alternated between trials. After placing the objects, the experimenter said "Hey look, there's a (target) here." The experimenter gazed at the center of the table rather than the object she was labeling because we wanted to preserve the referential ambiguity throughout the trial. The experimenter waited approximately two seconds (based on a visual metronome placed within view) before saying, "Can you put the (target) in the bucket?" She then pushed the object(s) forward within reach of the child, and placed a plastic bucket in the center of the table, also within reach of the child. Prior to the twelve experimental trials, there were two training trials: a one-familiar trial and a two-familiar trial, to acquaint the child with the procedure. A camera placed to the side of the experimenter captured the participant's face, so that looking behavior could be coded from video.

Coding procedure Videos were coded using DataVyu software (`http://datavyu.org`). First, each trial was divided into four temporal phases: a *label* phase, which began at the utterance of the target label and ended when the experimenter began to slide the objects, a *slide* phase, which encompassed the sliding of the objects into the child's reach, a *planning phase*, which began at the end of the slide and ended when the child touched an object, and a *response* phase, which began when the child touched an object and ended when the child released the object into the bucket. After onsets and offsets of these phases had been coded, the coder recorded the number of looks the child made to the experimenter during each phase. We opted to code the number of looks rather than the duration of looks because we felt that looks from the stimuli to the experimenter and vice versa might allow children to integrate social and nonsocial information to solve the problem of reference. A second coder coded the number of looks for a quarter of the trials for each participant to establish reliability. For Experiment 1, ##% of trials were given the same number of looks by both coders. For Experiment 2, ##% of trials were given the same number of looks by both coders.

Results and Discussion

Results of Experiment 1 are presented in Figure 2. To test our prediction that referential ambiguity (i.e., having two novel objects) would produce more social referencing, we fit mixed-effects linear regression models separately for each phase with the following structure: `number of looks ~ number of objects * familiarity * age in months + (number of objects + familiarity | SID)`. A single model with phase as a factor did not converge.

We did not find any main or interaction effects of number of objects, familiarity, or age on number of looks during the label or slide phases. However, we found an interaction effect of number of objects and familiarity during the planning ($\beta = 0.21$, $p < .001$) and response phases ($\beta = 0.6$, $p < .001$), such that 2-novel trials were associated with more looking. There was no interaction with age in either phase[2]. In summary, children looked to the experimenter more often when planning and executing a response under uncertainty. These results suggest that children were aware that they did not have sufficient knowledge to answer independently, and they attempted to resolve their uncertainty using social referencing.

We did not find the expected effect of referential ambiguity in the label phase. It is possible that children failed to predict that they would need more information until later in the trial, when they were actually faced with making a decision. Another possibility is that children's looking was at ceiling during the labeling phase, perhaps because children look at someone who is speaking regardless of the need for referential disambiguation. A third possibility is that this is an artifact of our design, in which the experimenter gazed at the center of the table rather than the referent of her label. Children may have realized that the experimenter's gaze direction during labeling was not informative. Experiment 2 tests this possibility and examines whether children's social referencing is sensitive to graded uncertainty.

Experiment 2

Experiment 2 was designed to replicate Experiment 1 and to investigate whether children's social referencing is sensitive to uncertainty based on graded evidence about a label's referent. Since we did not observe any difference between the one-familiar and one-novel trials, we eliminated single-object trials, leaving the 2-familiar and 2-novel trials. In addition, we added 1-novel-1-familiar trials ("mutual exclusivity trials"). For these trials, we expected that children would be able to infer the referent by excluding the familiar object as a possibility. We predicted that children might be less certain about their choice on these trials compared to when the label and referent were familiar to them (familiar trials), but more confident than when there are no cues to reference (novel trials).

(Markman, Wasow, & Hansen, 2003).

In addition, we manipulated between participants whether or not the experimenter's gaze during labeling was informative (she gazed at either the referent of her label or the center of the table), allowing us to determine whether children selectively reference gaze during labeling when gaze is expected to be informative. The manipulation of informativity of gaze during labeling also meant that participants in the referential gaze condition had an additional referential cue, which might decrease uncertainty in the remainder of the trial.

In Experiment 1, we did not observe an effect of age on looking. Thus, we restricted the current sample to 3- and 4-year-olds.

[2] `https://github.com/emilyfae/socref_uncert`

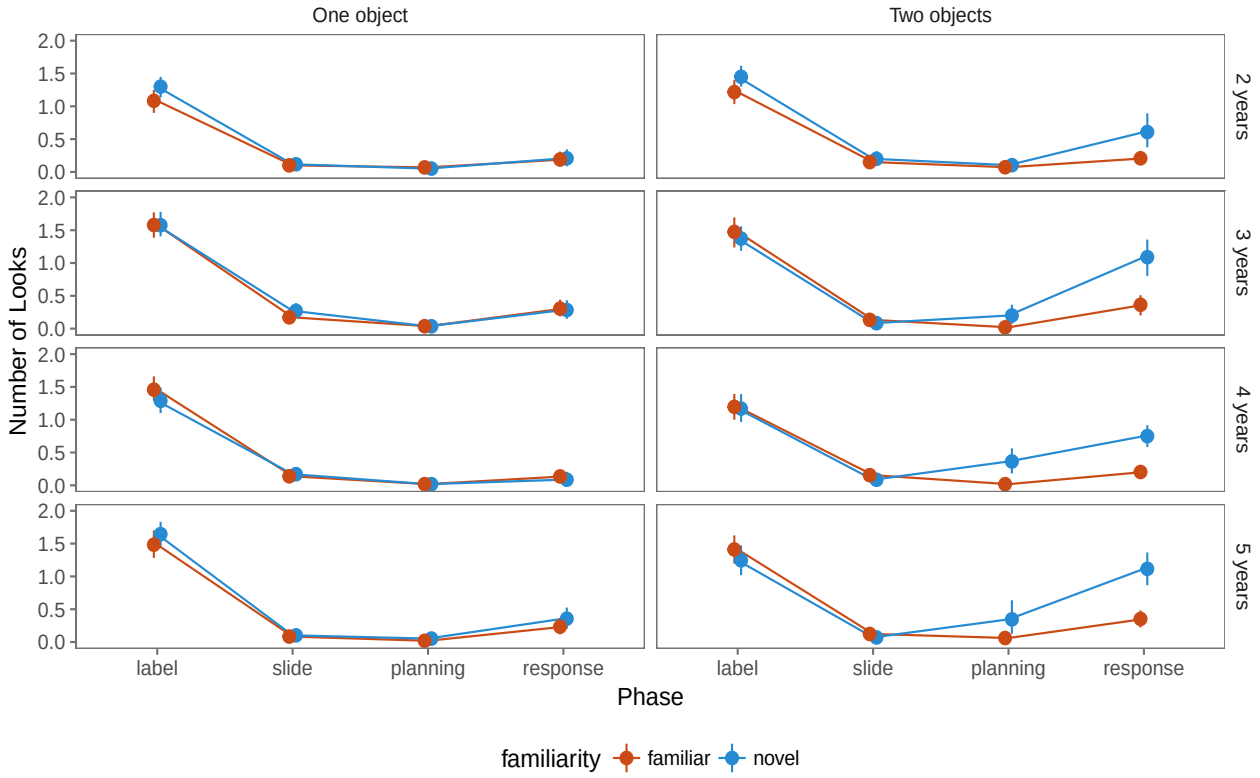

Figure 2: Results of Experiment 1. Number of looks to the experimenter across phases and conditions. Error bars are 95 percent confidence intervals.

Methods

Participants We recruited a planned sample of 80 children ages 3-4 years from the Children's Discovery Museum in San Jose, California[3]. The sample included 40 3-year-olds (mean age 42.89 months) and 40 4-year-olds (mean age 53.47 months). An additional 20 children participated but were removed from analyses because they heard English less than 75% of the time at home ($n = 9$), because they were unable to complete at least half of the trials in the task ($n = 7$), or due to experimenter or technical errors ($n = 4$).

Stimuli and Design The stimuli and design were similar to Experiment 1, except that we eliminated 1-object trials. Instead, we included three trial types: 2-familiar ("familiar"), 2-novel ("novel"), and 1-novel-1-familiar ("mutual exclusivity"). There were four of each trial type, totaling twelve trials. In addition, we manipulated the experimenter's gaze behavior between participants. For half of the participants, she looked at the center of the table on every trial; for the remaining half, she looked at the object she referred to on every trial.

Procedure The procedure was identical to Experiment 1, except that there were three practice trials rather than two, so that children could experience every trial type.

[3]Planned sample size, exclusion criteria, and analysis plan pre-registered at https://osf.io/y7mvt/

Results and Discussion

Results of Experiment 2 are presented in Figure 3. To quantify the main and interactive effects of familiarity, gaze informativity, phase, and age on social referencing, we fit a mixed-effects linear regression model with the following structure: `number of looks ~ familiarity * age in months * gaze * phase + (familiarity | SID)`. In contrast to Experiment 1, a model with phase as a predictor converged.

We were interested in several questions. First, do children reference a speaker more often when the objects and label are novel? Phase interacted with familiarity such that the response phase of novel trials was associated with significantly more looks ($\beta = 0.51$, $p < .001$). This is consistent with our finding from the linear model of the response phase in Experiment 1. However, in contrast to Experiment 1, we did not observe that looking was significantly greater for novel trials in the planning phase.

We were also interested in whether mutual exclusivity trials would elicit an intermediate amount of social referencing. We observed a three-way interaction of familiarity, gaze, and phase, such that the response phase of mutual exclusivity trials in the no-referential-gaze condition was associated with significantly more looks ($\beta = 0.39$, $p < .01$). In sum, mutual exclusivity trials were associated with greater looking during the response phase when the experimenter provided informative gaze compared to when she did not. This find-

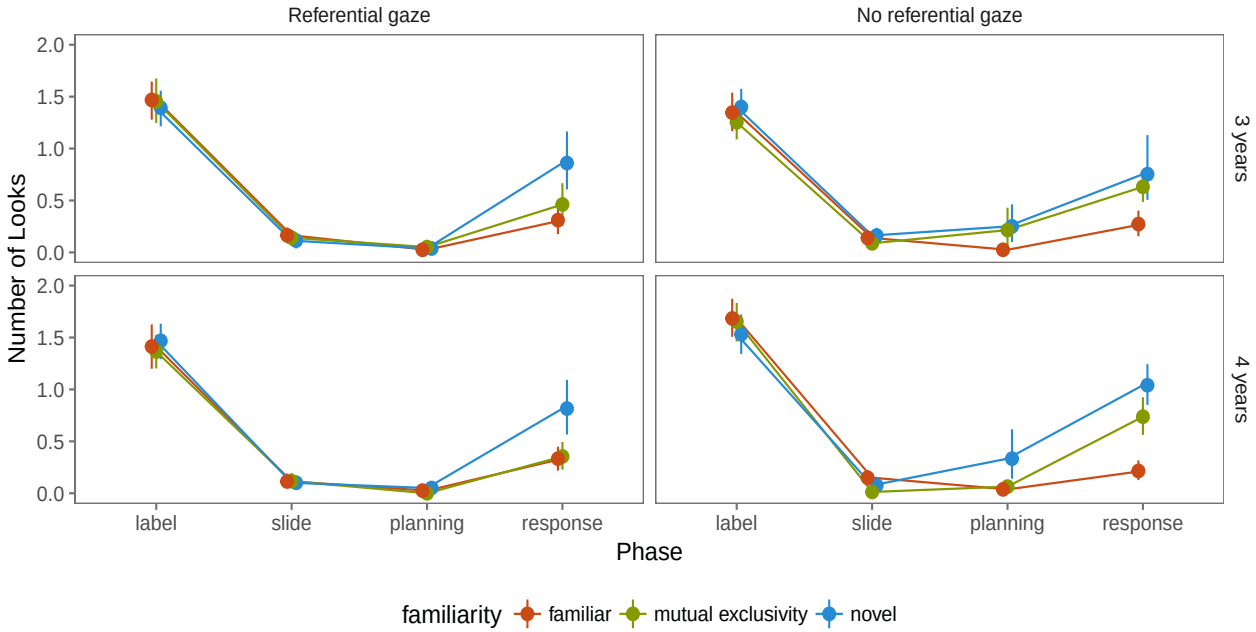

Figure 3: Results of Experiment 2. Number of looks to the experimenter across phases and conditions. Error bars are 95 percent confidence intervals.

ing is intriguing given that children should be able to solve mutual exclusivity trials without gaze information. Instead, it seems that they remain somewhat uncertain while executing a decision if mutual exclusivity is their only cue to reference, but this uncertainty is resolved if the experimenter gazes at the correct object during labeling. This provides evidence for sensitivity to graded evidence.

Finally, we observed a four-way interaction such that the response phase of novel trials in the gaze condition was associated with more looking with increasing age ($\beta = 0.06$, $p < .01$), suggesting that children may become more selective in their social referencing as they get older. It may be that children improve in their ability to monitor the need for disambiguating information, or they may become more likely to recognize that social information can be a source of disambiguation.

Lastly, we again did not find selective social referencing during the label phase, even when referential gaze was available. This rules out the possibility that children were less selective during this phase because they learned that gaze direction was not informative.

General Discussion

Preschoolers quickly learn new concepts, rules, and language. They also actively explore and ask questions in ways that seem targeted to maximize learning (Chouinard, Harris, & Maratsos, 2007; L. E. Schulz & Bonawitz, 2007). However, we still have an incomplete understanding of young children's ability to monitor their own mental states, in particular, their epistemic uncertainty. Do children monitor their own uncertainty to guide information-seeking behaviors, or are external features of the environment sufficient to guide these behaviors (e.g., children might ask for help with a complex looking toy in response to perceptual features rather than epistemic states). Here, we examined a spontaneous information-seeking behavior, social referencing, and its selectivity with regard to epistemic uncertainty among preschool-aged children.

We found strong evidence of selective social referencing under referential ambiguity when children were making their decision about which object was the target. In Experiment 1, we additionally found evidence for selective social referencing as children planned their decision, though this was not replicated in Experiment 2. We speculate that children may have referenced the speaker during the decision process because they expected confirmation of the accuracy of their choice, either implicitly through the adult's facial expressions, or through explicit feedback.

Importantly, we also found evidence for selectivity in social referencing based on graded uncertainty. In Experiment 2, we manipulated the amount of evidence available to children by including mutual exclusivity trials and manipulating whether or not the speaker's gaze direction was informative. We found that children treated mutual exclusivity trials more like familiar trials when they had received helpful gaze, but more like novel trials when they had not, suggesting that the combination of mutual exclusivity cues and gaze direction cues were required for children to feel confident about the object-label mapping. It is possible that they remain uncertain about a new label even after they have acquired it, if they have only heard it once and not received confirmation of its accuracy, for example, through gaze monitoring. Importantly,

informative gaze during labeling did not lessen the amount of social referencing during the response phase for novel trials, suggesting that gaze information alone was not sufficient to reduce uncertainty.

On the other hand, we found no evidence for selectivity as the object was being labeled, or as the objects were being slid into reach. One interpretation of this pattern of results is that preschool-aged children do not recognize the need for disambiguating information when a referent is ambiguous until they are in the position of needing to make a decision. However, another possibility is that children spontaneously look at a speaker regardless of the need for disambiguating information, and additional looking on top of this baseline was not needed or possible. A related possibility is that the labeling phase of our task was too fast for children to produce extra looking on top of baseline in response to uncertainty. A follow-up to the present work that includes a longer labeling period or a greater reward tradeoff associated with different attentional options would help to distinguish among these possibilities.

Overall, these results provide evidence that preschool-aged children monitor graded uncertainty in their mental representations and act on that uncertainty through information-gathering behaviors. These findings contribute to an emerging view of children's early learning as active and driven by probabilistic evidence (e.g., L. Schulz, 2012; Xu & Kushnir, 2013).

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